## 2. THE 2004, DECEMBER NORTHERN SUMATRA EARTHQUAKE AND THE INDIAN OCEAN TSUNAMIS

### 2.1 An Overview

On December 26, 2004, 00:58 (UTC), 07:58 (Local Time, Indonesia), a great earthquake occurred off the west coast of northern Sumatra, Indonesia. The magnitude of this earthquake was 9.0 and this was the fourth largest earthquake in the world since 1900. The earthquake occurred on the plate boundary that India plate subducts beneath the overriding Burma plate. Figure 2.1 shows the tectonic setting of the northern Indian Ocean [1]. The main shock occurred off the west coast of Sumatra Island and the aftershocks extended to the northward as long as approximately 1,000 km long of rupture zone.

The tsunami accompanied with this earthquake propagated in the entire Indian Ocean and caused extensive and significant damage. The reported number of casualties are approximately 300,000 (230,000 killed in Indonesia by the earthquake and tsunami, at least more than 29,000 killed in Sri Lanka, more than 10,000 in India, more than 5,000 in Thailand, and 82 killed in the Maldives by tsunamis ) and more than 22,000 are still missing.

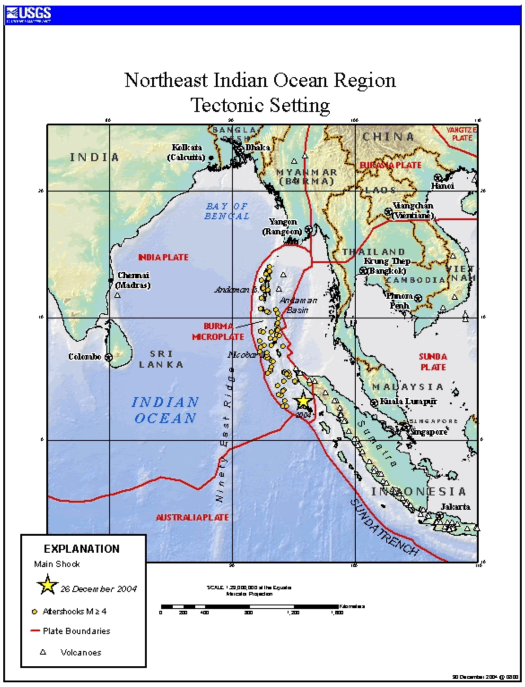


Figure 2.1 Tectonic setting of the Indian Ocean (USGS)

Figure 2.2 shows the estimated tsunami travel time in the Indian Ocean [(2)]. The tsunami attacked the coasts of Thailand and Sri Lanka in 2 hours, the Maldives within 4 hours, and east Africa in 10 hours. The tsunamis were observed at a great number of tidal stations in the Indian Ocean, and even in Antarctica [(3)].

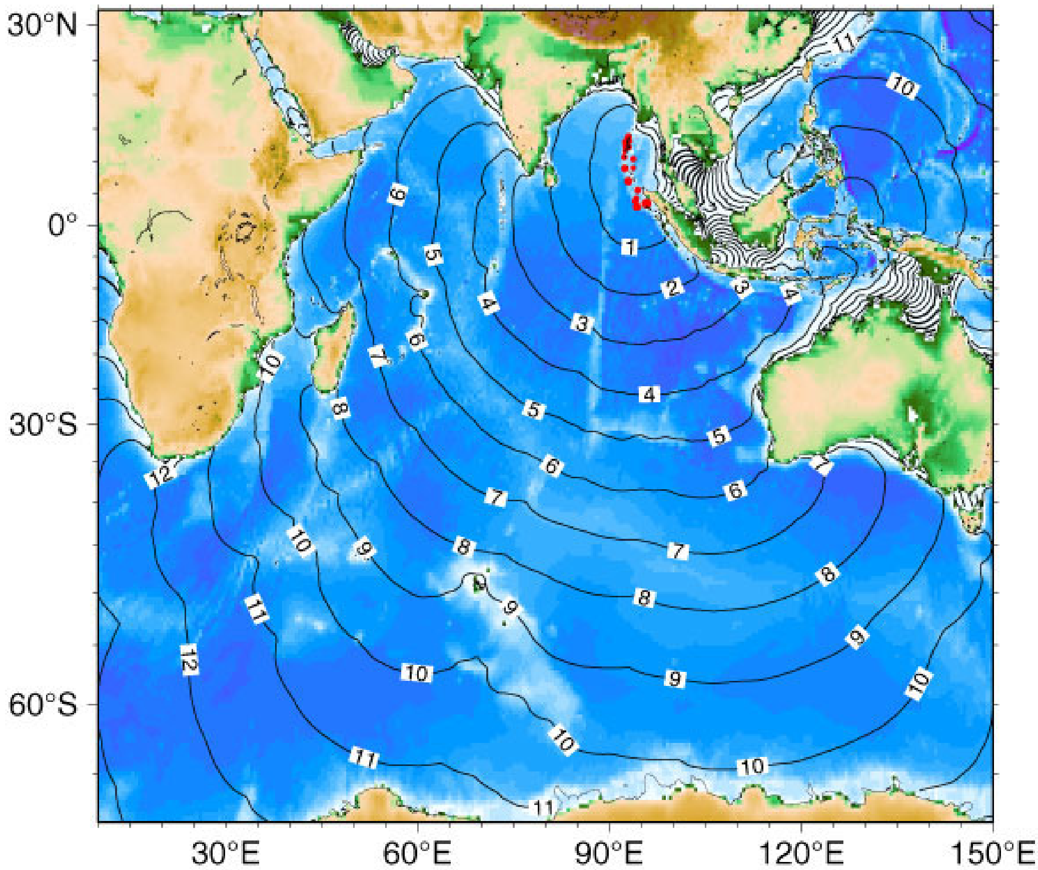


Figure 2.2 The computed tsunami travel time within the Indian Ocean (Computed and drawn by Kenji Satake, AIST, Japan)

## 2.2 Numerical Modeling of Tsunami

Focusing on comprehending the tsunami propagation characteristics in the Indian Ocean, the numerical modeling of tsunami is performed by using TUNAMI code developed by Tohoku University, Japan [(4)]. The model is based on the linear shallow water equations of spherical co-ordinate system. Figure 2.3 shows the computational domain and the sea bottom topography of the Indian Ocean. We use the 2 arc-minute grids of bathymetry of ETOPO2, provided by the National Geophysical Data Center [(5)].

We assume that the sea bottom deformation due to the earthquake pushes up / draws down the overlying water, forming the initial sea surface of tsunami. Table 2.1 indicates the fault parameters to compute the sea bottom deformation. Strike is the azimuth of the fault plane (fault strike line) measured from North, and dip is the azimuth of the fault plane measured from the horizontal line. Slip is the angle of the fault slip direction measured from the horizontal line. The detailed definitions of the parameters are indicated in the appendix of this chapter. Here, the rupture zone is divided into the two subfaults. We applied the theory of Okada (1985) to obtain the sea bottom deformation [6].

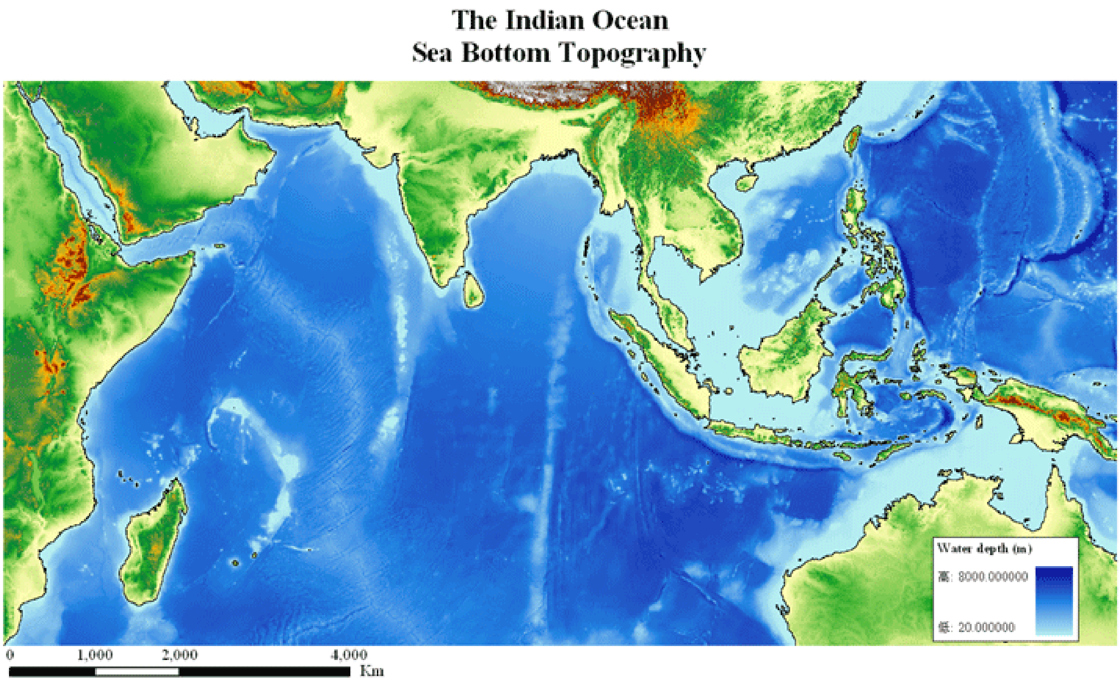


Figure 2.3 The computational domain and the sea bottom topography of the Indian Ocean

Table 2.1 Fault parameters to compute the initial sea surface profile of tsunami

| | 1st. segment (southern part) | 2nd. segment (northern part) |
|---|---|---|
| Strike, Dip, and Slip (degree) | 329, 15, and 90 | 345, 15, and 90 |
| L and W (km) | 500 and 150 | 400 and 150 |
| Dislocation (m) | 11 m | 11 m |
| Fault depth (km) | 10 km | 10 km |

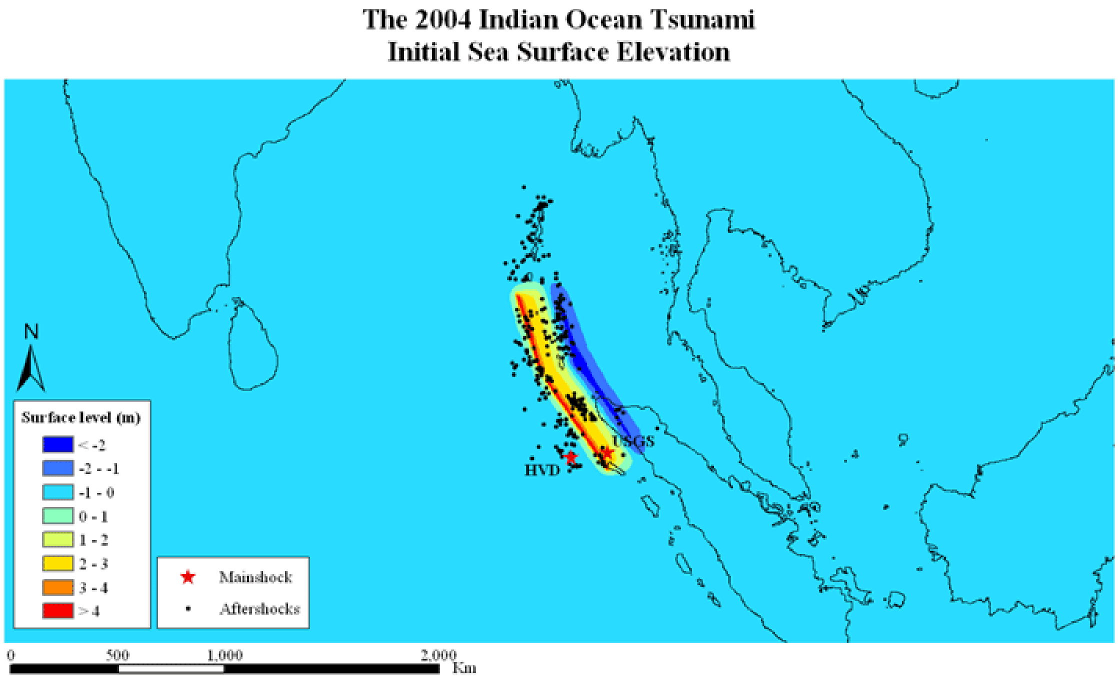


Figure 2.4 Computed sea bottom deformation due to the 2004 December Sumatra earthquake

Figure 2.4 shows the computed sea bottom deformation, i.e. the initial sea surface profile of tsunami. The black dots indicate the distribution of aftershocks. The tectonics of this region suggests the thrust fault as the focal mechanism, generating the subsidence of the coast of northern Sumatra Island. The maximum uplift of the sea bottom is computed as 4.7 m , and maximum subsidence as 2.7 m.

Figure 2.5 shows the snap shots of tsunami propagation 0, 30, 60, 120, 150, 180, and 210 minutes after the earthquake. Also, Figure 2.6 is the distribution of computed maximum tsunami height in the entire Indian Ocean. The model results show that the tsunami energy was extended to the entire coasts of the Indian Ocean. Especially, significant tsunami attacked the coasts of northern Sumatra and Thailand, which are close to the tsunami source region. Also, the energy radiation pattern suggests that the tsunami had the directivities to propagate westward and eastward, attacking the coasts of Sri Lanka, and Maldives. Figure 2.7, 2.8, and 2.9 are the computed local tsunami heights along the coasts of northern Sumatra, Thailand, Sri Lanka, southern India, and the Maldives. These results are qualitatively consistent with the significance of reported tsunami damage and casualties.

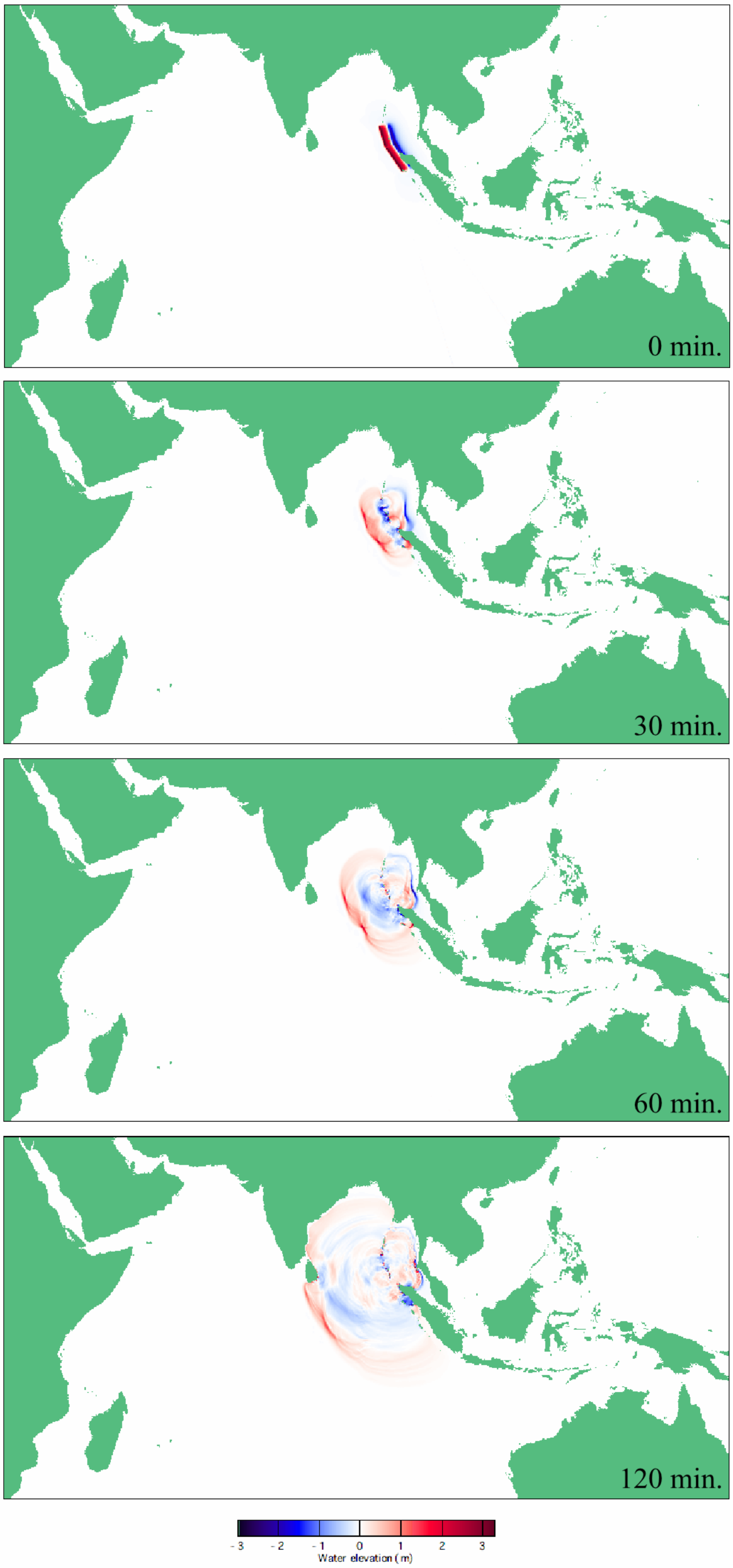


Figure 2.5  Snapshots of the modeled tsunami propagating in the Indian Ocean

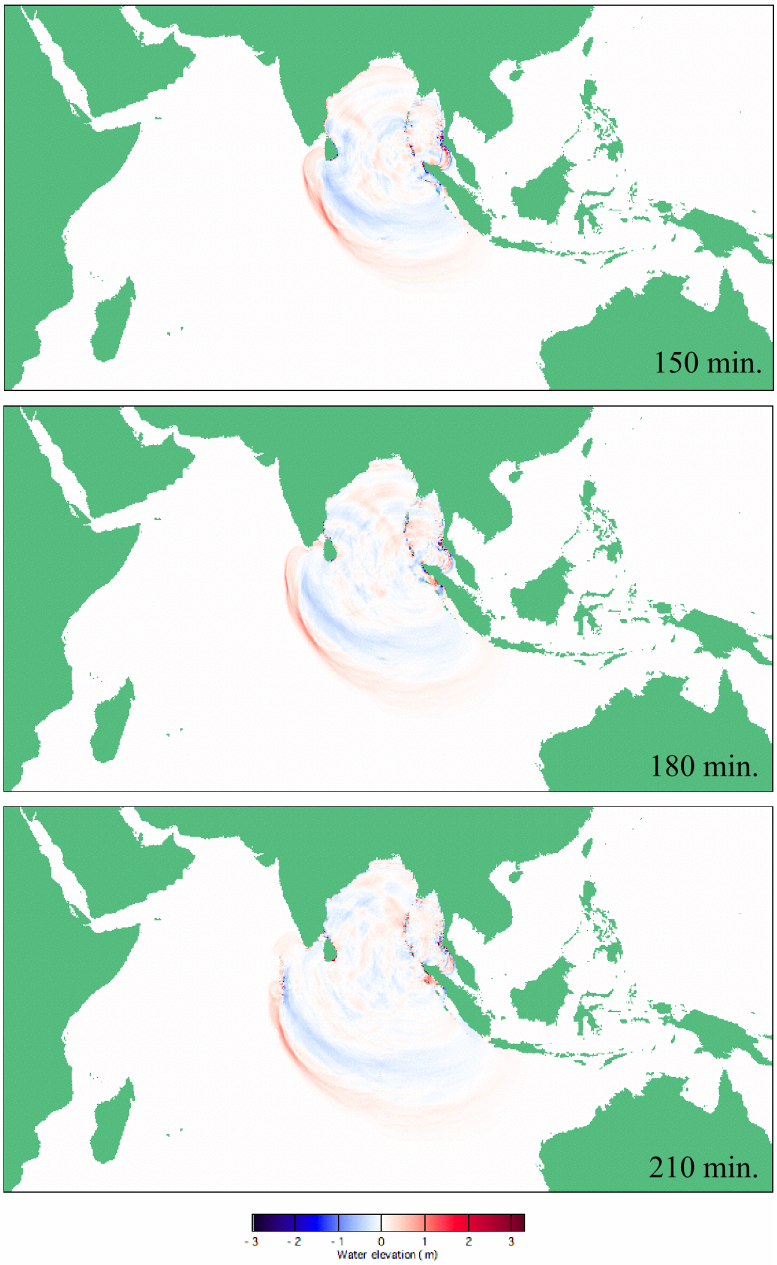


Figure 2.5 (continued) Snapshots of the modeled tsunami propagating in the Indian Ocean

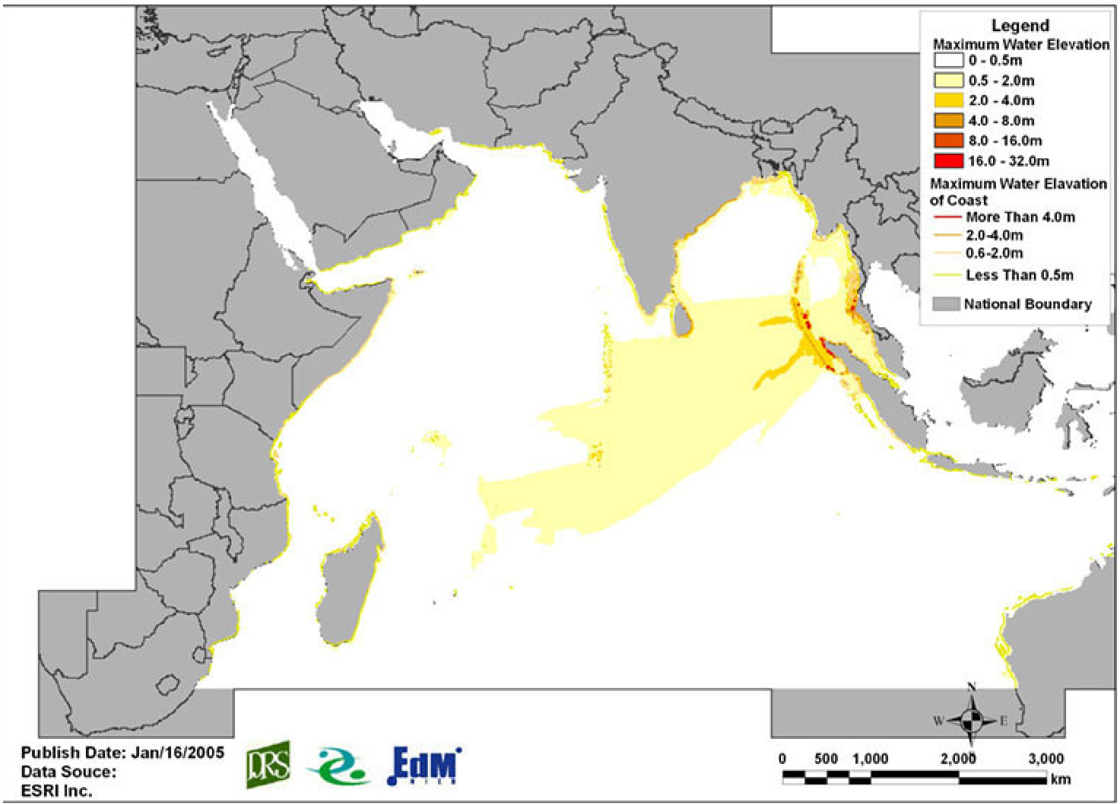


Figure 2.6 Distribution of computed maximum tsunami height

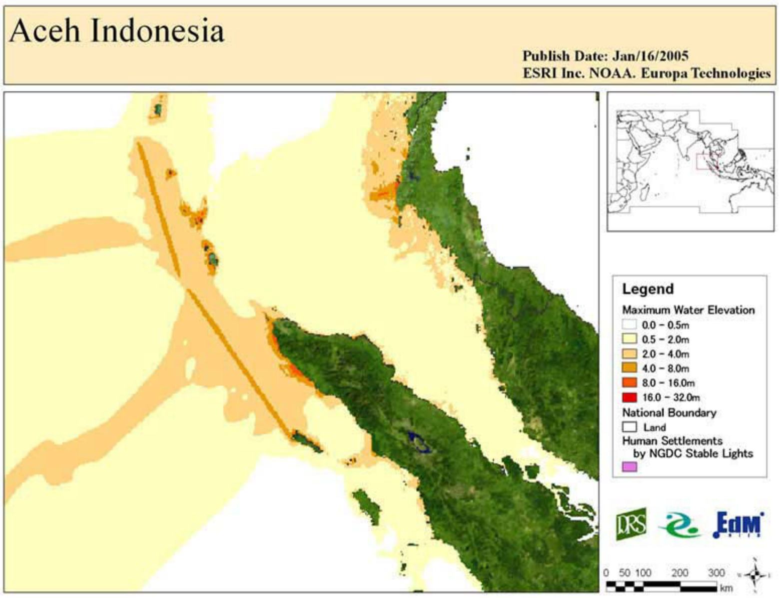


Figure 2.7 Computed local tsunami height along the coasts of northern Sumatra and Thailand

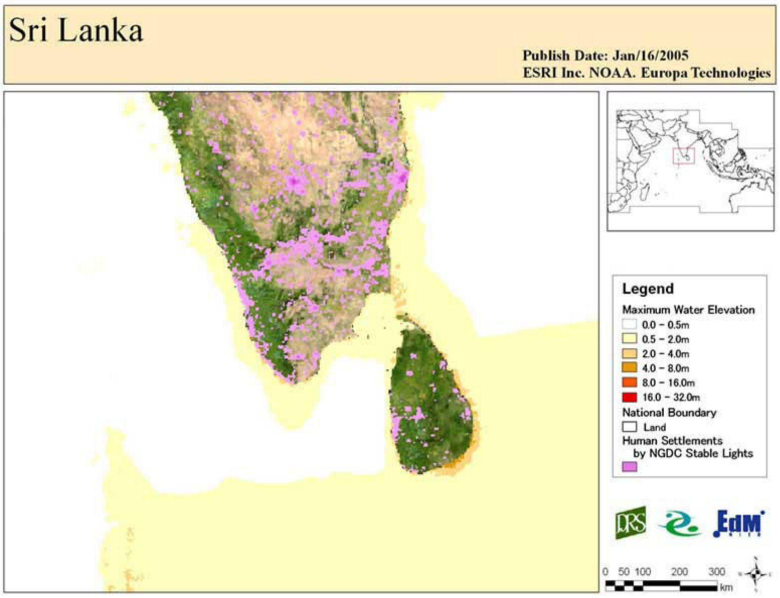


Figure 2.8 Computed local tsunami height along the coasts of Sri Lanka and southern India

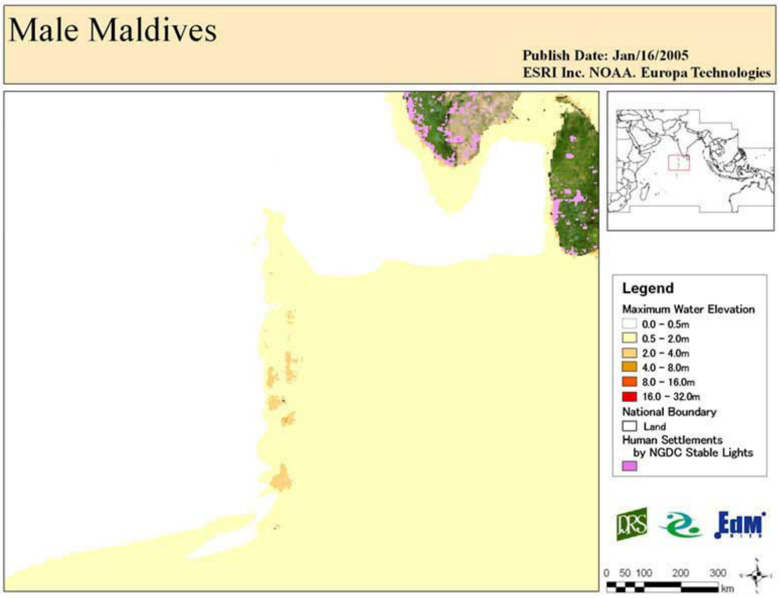


Figure 2.9 Computed local tsunami height along the coasts of the Maldives

## 2.3 Summary

From the preliminary numerical model runs, we attempted to comprehend the propagation characteristics of the 2004 December Indian Ocean tsunami. The model results are qualitatively consistent with the reported damage. However, we have not known yet the detailed source mechanisms; how significant tsunami along the coast of the source region could be generated by the M9.0 earthquake, and the whole picture of tsunami propagation characteristics and the tsunami risk within the Indian Ocean. Further investigations should be carried out with the results of post tsunami survey, and the analysis of observed tsunami records, strong ground motions, and measurement of crustal deformation of the source region.

References

(1) Web site of United States Geological Survey (2004) :
http://wwwneic.cr.usgs.gov/neis/eq_depot/2004/eq_041226/

(2) Kenji Satake, AIST, Japan (2004) :
http://staff.aist.go.jp/kenji.satake/Sumatra-E.html

(3) Japan Coast Guard (2004) :
http://www1.kaiho.mlit.go.jp/KANKYO/KAIYO/jare/tide/tide_index.html

(4) Imamura, F. (2004) : Review of Tsunami Simulation with a Finite Difference Method, in Long-Wave Runup Models, edited by H. Yeh, P. Liu, and C. Synolakis, World Scientific, River Edge, NJ, pp.43-87.

(5) Web site of National Geophysical Data Center :
http://www.ngdc.noaa.gov/mgg/image/2minrelief.html

(6) Okada, Y. (1985) : Surface Deformation due to Shear and Tensile Faults in a Half-space, Bulletin of the Seismological Society of America, 75 (4), pp.1135-1154.

Appendix : Fault parameters