Remote Sensing, GIS, and Modeling Technologies Enhance the Synergic Capability to Comprehend the Impact of Great Tsunami Disaster

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INTRODUCTION

Since the 2004 Indian Ocean tsunami disaster, lots of tsunami damage detection technologies have been developed and validated. Especially, high-resolution satellite imagery enhances the capabilities for quantitative detection of local tsunami damage, which have been one of the most significant issues for post tsunami disaster response. However, in other words, the extensive scale of catastrophic tsunami makes it difficult to comprehend overall impact of great tsunami disaster within the entire Ocean, and also may disenable to prioritize how the limited resources of state-of-the-art technologies should be deployed immediately in such limited amount of time and information.

In order to comprehend the impact of tsunami disaster in macro scale, the authors develop a GIS-based model to estimate the potential number of exposed population against tsunami disaster, called potential tsunami exposure (PTE). The present model was validated with the event of the 2004 Indian Ocean tsunami disaster, and attempted to estimate the potential tsunami exposure within the Indian Ocean to understand the vulnerabilities of coastal community against the next-possible great tsunami disaster.

MODELING THE 2004 INDIAN OCEAN TSUNAMI

We performed the numerical model of the trans-oceanic propagation of the 2004 Indian Ocean Tsunami. The model is based on a set of linearized shallow water equations, and discretized by the Staggered Leap-frog finite difference scheme in the spherical co-ordinate system[1)]. As the initial condition, we assume instantaneous displacement of the sea surface identical to the vertical sea floor displacement shown in Figure 1. The assumed fault structures are indicated in Table 1, as thrust faults dipping eastward with a total rupture area of 900km by 150km. The amount of fault slip was adjusted to provide surface displacements[2)] that are reasonably consistent with the reported subsidence along the coast of Sumatra Island.

The bathymetry data used is 2-minute global relief data (ETOPO2) provided by the National Geophysical Data Center.[3)]

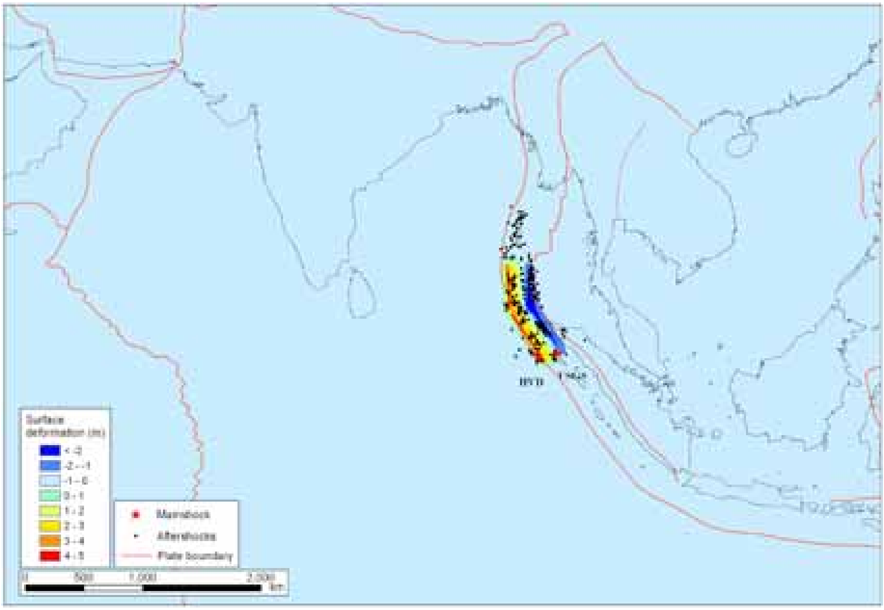

Figure 1 Tsunami source model of the 2004 Indian Ocean Tsunami. The fault is divided into two segments to be consistent with the aftershock distribution and tectonic structure. We decided the focal mechanisms based on Harvard University's CMT solutions.

Table 1 Dimension of fault and source parameters for the present study.

	Southern Segment	Northern Segment
L / W (km)	500 / 150	400 / 150
Strike / Dip / Slip (degree)	329 / 15 / 90	358 / 15 / 90
Depth (km)	10	10
Dislocation (m)	11	11
Origin (Longitude / Latitude)	94.8N / 2.5N	92.0E / 6.5N

MODEL VALIDATION BY THE SATELLITE ALTIMETRY DATA

Tsunami propagation model is validated by satellite altimetry data of Jason-1[4)], which measured the sea surface level of the Indian Ocean approximately 2 hours after the earthquake occurred. Figure 2 indicates the snapshot of the tsunami propagation model approximately 2 hours after the earthquake occurred, and also the comparison of the measured sea surface level by Jason-1 altimetry and the modeled tsunami height along the Jason-1 109 track. We can see a good agreement in terms of the tsunami front propagating to northern and southern direction.

Jason-1 altimetry data enables the tsunami modelers to validate their models more precisely. So far, the model validation has been performed by using post tsunami survey data such as tsunami run-up height, geodetic data such as deformation and uplift of the ground surface, and observed tsunami records. Also, collecting these data have taken lots of time, and this fact constrains the modelers from obtaining the quick estimate of tsunami. The advantage of Jason-1 altimetry data is that it captures the spatial extent of tsunami propagation within the Ocean.

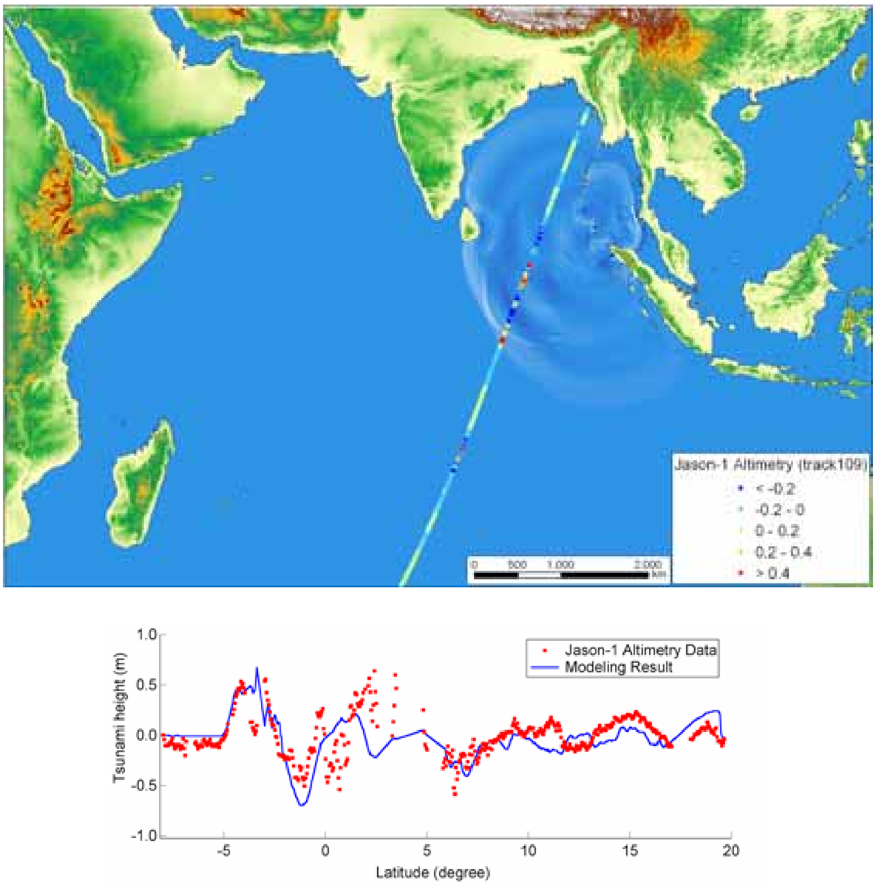

Figure 2 Snapshot of the tsunami propagation model approximately 2 hours after the earthquake occurred (Upper). The model validation is also shown by the comparison of the measured sea surface level by Jason-1 altimetry and the modeled tsunami height along the Jason-1 109 track (Lower).

EXPLORE THE VULNERABILITY AGAINST TSUNAMI DISASTER

In order to address the vulnerabilities along the coast of the Indian Ocean, we explore the spatial criteria to count Potential Tsunami Exposure (PTE), that is the number of population exposed against the arbitrary height of tsunami along the coast, so that actual number of casualties by the Indian Ocean tsunami disaster corresponds to population obtained within the affected area considered by maximum tsunami height, distance from the shoreline and land elevation. PTE is defined as the equation (1), the population count, that is exposed against the arbitrary height of tsunami 'η' within an evaluation area 'i ' which is expressed as the aggregation of evaluation unit area 'j '.

$$PTE(\eta)_i = \sum_{j=1}^{J} P_{ij} \tag{1}$$

PTE can be obtained if the number of population along the coast, and estimated / measured tsunami height distribution are known. Here, we defined the evaluation unit as each coastal grid of 30 seconds by 30 seconds, and obtained the number of exposed population against arbitrary tsunami height estimated by the numerical model, by using GIS analysis. For the analysis, we use LandScan Global Population Database (LandScan2003) provided by Oak Ridge National Laboratory[5)], and Shuttle Radar Topography Mission Data (SRTM Data) from NASA[6)]. Figure 3 shows the estimated tsunami height along the coast of the Indian Ocean, which is used to obtain PTE. Also, Figure 4 illustrates the population data from LandScan2003.

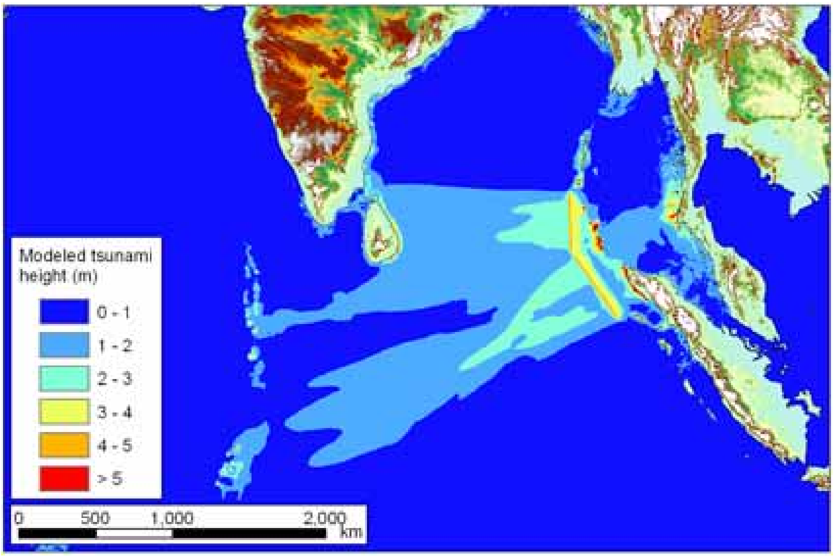

Figure 3 Estimated Tsunami Height by the numerical model. Based on the numerical model results, we can identify the spatial distributions of tsunami height that attacked the coastal communities.

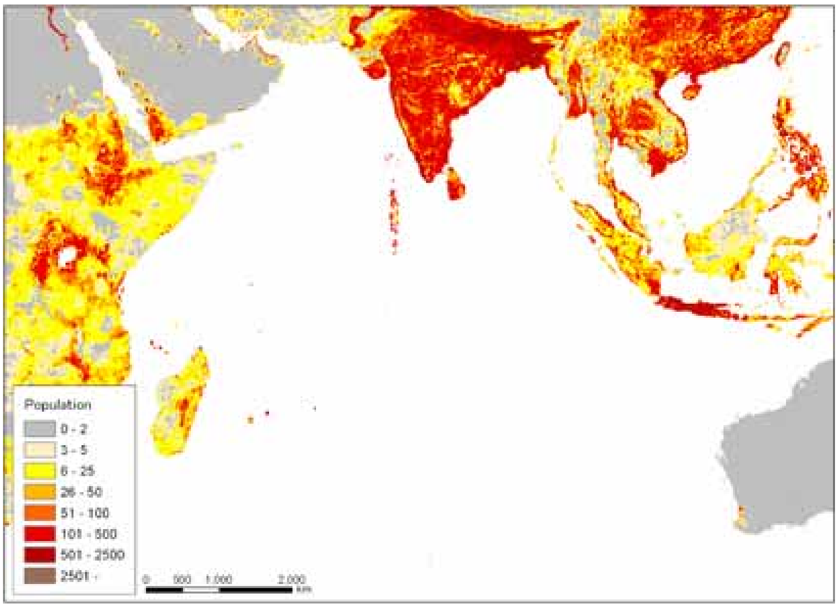

Figure 4 Population data from LandScan2003. LandScan2003 indicates the population within the grid of 30 seconds by 30 seconds. Thus, combined with the magnitude of natural hazards, we can identify the vulnerability.

POTENTIAL TSUNAMI EXPOSURE (PTE) AGAINST THE 2004 INDIAN OCEAN TSUNAMI DISASTER

Figure 5 indicates the distribution of accumulative number of PTE, which means the number of population exposed against the tsunami more than arbitrary height. We can find a unique value of tsunami height that corresponds to the actual or reported number of casualties. This number can be interpreted as the quantitative estimate of local tsunami vulnerability along the coast as shown in Table 2. For instance, the vulnerability of Indonesia coast for the 2004 event was obtained as 2.07 (m), that was the corresponding tsunami height to the reported number of casualties (236,169) in Indonesia. The lower value of this number means higher vulnerability. In the entire Indian Ocean, the tsunami height that possibly caused 300 thousand of casualties was obtained as 4.09 (m) by using the diagram.

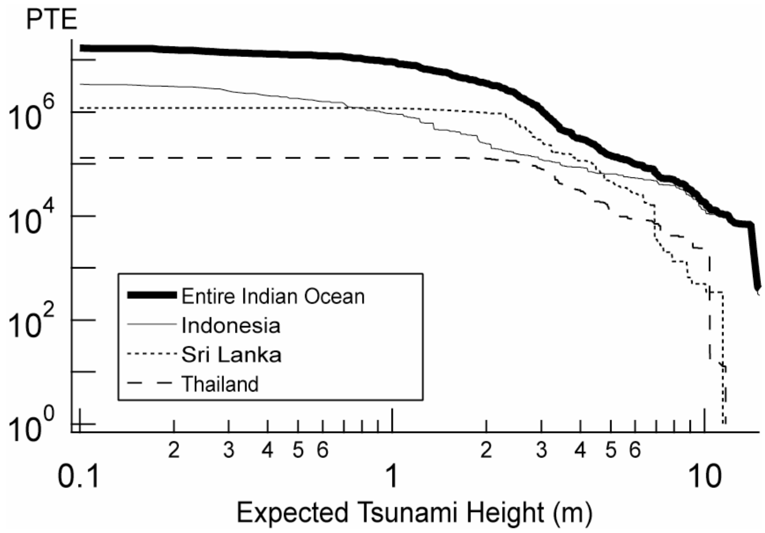

Figure 5 Accumulative PTE as a function of expected tsunami height in case of the 2004 Indian Ocean tsunami disaster.

Table 2 Vulnerabilities against tsunami disaster along the Indian Ocean in case of the 2004 event.

	Entire Indian Ocean	Indonesia	Sri Lanka	India	Thailand
Reported casualties	297,046	236,169	35,672	16,416	8,388
Vulnerability (m)	4.09	2.07	5.38	5.86	5.92

IS THE 2004 EVENT THE WORST CASE SCENARIO?

None of us can answer the question, what is the worst case scenario to be considered for the coastal communities of the Indian Ocean. The present analysis suggests an estimate. In addition to the 2004 event, we assume possible 4 scenarios of M9 class earthquakes along the plate boundary shown in Figure 6, and estimated the number of expected tsunami casualties of Table 3. The number of casualties were obtained by the estimation of tsunami height for each scenario and the population exposed against the arbitrary tsunami height as the threshold shown in the left table, i.e. 2.07 (m) is the vulnerability of Indonesia and 5.71 (m) is the averaged value of vulnerabilities of Sri Lanka, India and Thailand during the 2004 Indian Ocean tsunami disaster. We found that the 2004 event might not be the worst case scenario within the Indian Ocean tsunami to be considered in the future.

SUMMARY

Using satellite altimetry, GIS database and numerical modeling technique, the authors developed a method to obtain quick estimate in terms of the impact of the great tsunami disaster. We believe that these estimates can address the area that more precise damage detection technologies using high-resolution satellite imagery or any other remote sensing data should be deployed within the limited amount of time and resources. During the 2004 Indian Ocean tsunami disaster, we spent lots of time to comprehend the overall damage within the entire Indian Ocean. The authors strongly suggest that research communities from various fields should collaborate to enhance the capability for quick and effective post tsunami disaster response for the next possible tsunami disaster.

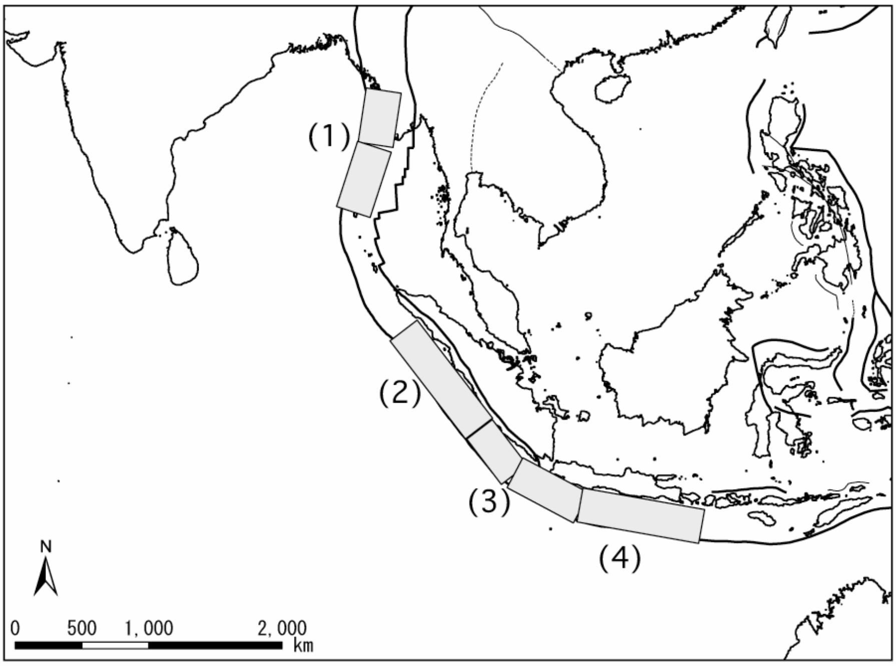

Figure 6 Hypothetical earthquake scenarios along the Indian Ocean.

Table 3 Estimated casualties by the hypothetical tsunami scenarios.

	Estimated casualty (Threshold : 2.07m)	Estimated casualty (Threshold : 5.71m)
Scenario (1)	3,310,923	708,323
Scenario (2)	1,223,236	121,574
Scenario (3)	1,538,711	631,332
Scenario (4)	1,362,972	447,135

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