DUAL-SCALE MAPPING OF DISASTER-AFFECTED AREAS: A CASE STUDY OF THE 2004 TSUNAMI DISASTER IN THAILAND

Tuong Thuy Vu, Masashi Matsuoka, Fumio Yamazaki

ABSTRACT: This paper presents the performance of a dual-scale mapping system on tsunami-affected areas in Thailand. The key factor of the system is the capability to effectively retrieve, analyze and provide the results on either macro-scale (medium spatial resolution) or micro-scale (high spatial resolution) depending on the user's decision. It takes advantage of large covered areas by medium resolution satellite images and detailed information by high resolution satellite images. The system is started by collecting and analyzing medium satellite images such as ASTER of the tsunami-affected areas by a set of macro-scale algorithms. The affected areas might be successfully extracted at this scale. If not or the user requests the detailed mapping of a specific area, the system is switched to micro-scale. Geographical extent of the focused area is reported by the user's selection for the collection of high resolution satellite images such as QuickBird or IKONOS. Subsequently, they are analyzed by micro-scale algorithms. This mechanism is meaningful in providing geo-information for damage assessment at an early stage because it acquires and analyzes only necessary data by suitable processing methods. A further study includes the accomplishment of system development with graphic user interface in a GIS environment. This system can be also extended to other types of disasters by developing new suitable sets of processing algorithms.

KEYWORDS: dual-scale; tsunami; image processing; remote sensing

1. INTRDUCTION

For decades, remote sensing techniques have been extensively employed in hazard mapping and disaster mitigation. There have been plenty of published works and real implementations of remote sensing in hazard mapping such as flood mapping (Barber et al. 1996), displacement mapping due to earthquakes (Massonnet et al. 1993), earthquake damage detection (Matsuoka and Yamazaki 1999), landslide mapping (Singhroy and Mattar 2000, Vohora and Donoghue 2004), and volcano observation (Mouginis-Mark et al. 1991, Andres and Rose 1995). The most significant improvement which has influenced the mapping capabilities was the commercialization of high spatial resolution satellite images such as IKONOS and QuickBird. They have been employed in earthquake damage detection (Vu et al. 2005a, Yamazaki et al. 2005) or landslide mapping (Vohora and Donoghue 2004), etc. Depending on the nature of a catastrophe and the availability of satellite data, one or some kinds of satellite images are acquired and analyzed. In addition, the selection of satellite image also depends on the analyzer's expertise; "which satellite data must be used?" and "which methodology is suitable?" are very crucial. As numerous data sources are available nowadays when a catastrophe occurs, the most important concern is finding an efficient solution to quickly grasp the necessary information, i.e. the maps of the affected areas. Obviously, there is a trade-off between the total cost including data acquisition and computational time and the level of detail. Exploiting the scale property in developing an integrated framework can be a cost-effective solution to use remotely sensed data in quick hazard mapping and damage assessment.

An integrated processing framework for medium spatial resolution optical satellite images (Landsat or ASTER), high spatial resolution optical satellite images (QuickBird or IKONOS) and digital elevation data in detection of tsunami-affected areas is developed. The key point of this framework is processing only necessary data to provide just enough information. The high resolution data is required only when analyzed results on macro-scale could not provide enough information or the site is of a specific concern. The processing flow moves upwards from macro-scale (medium resolution data) to micro-scale (high resolution data). The case study chose the tsunami affected-areas in Thailand, which were devastated by the 2004 Indian Ocean tsunami. The following section describes the idea of dual-scale mapping applied in mapping tsunami-affected areas. It is followed by the descriptions of detailed processing on macro-scale and micro-scale by using satellite images acquired over the tsunami-affected areas in the south Thailand.

2. PROPOSED DUAL-SCALE MAPPING SYSTEM

Objects in the world appear in the ways depending on the scale of observation (Lindeberg 1993). Satellite images acquired by different sensors present an object in different ways. As a result, the level of detail and the extent of a scene are different. For instance, a Landsat multi-spectral scene covers an area of 185 x 172 km^2 with 30 m spatial resolution and a QuickBird scene covers an area of 16.5 x 16.5 km^2 with 2.4 m spatial resolution. It is fast and easy to figure out the extent of a catastrophe by using a coarser image but not in detail. A small change is also not detectable from such a coarse image. On the contrary, it is very costly and time consuming to cover the entire affected areas only by high spatial resolution images. For quick mapping, the trade-off between these factors should be concerned. A framework to integrate data on two different scales is proposed as described below.

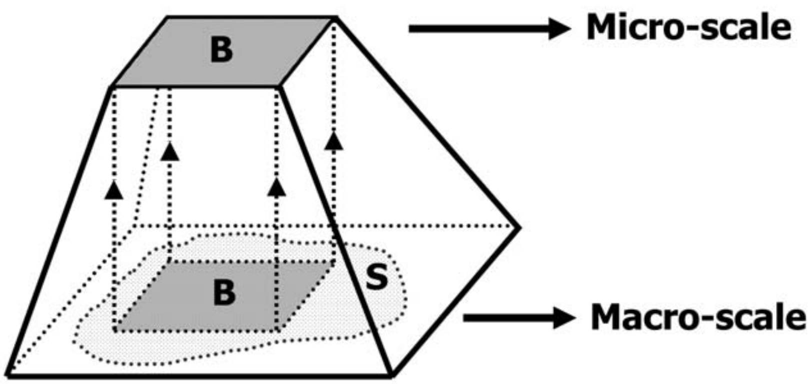

Figure 1. Illustration of dual-scale mapping idea

Figure 1 demonstrates the simple idea of dual-scale mapping. Starting from a macro-scale, a set of algorithms to search data and to detect affected areas are applied. Let S is a detected set on a macro-scale and B is a subset of S, i.e. $B \subseteq S$. Because B is with specific concern for more detailed mapping, its geographic extent is mapped on micro-scale to search for the corresponding data on this scale. Subsequently, micro-scale detection algorithms are applied. It is obvious to estimate how much the acquisition cost can be reduced by using this dual-scale link. Moreover, the micro-scale algorithms are generally much more complicated than the macro-scale ones. The dual-scale mapping carries out such complicated micro-scale algorithms in a smaller extent. The diagram of the proposed system is shown in Figure 2.

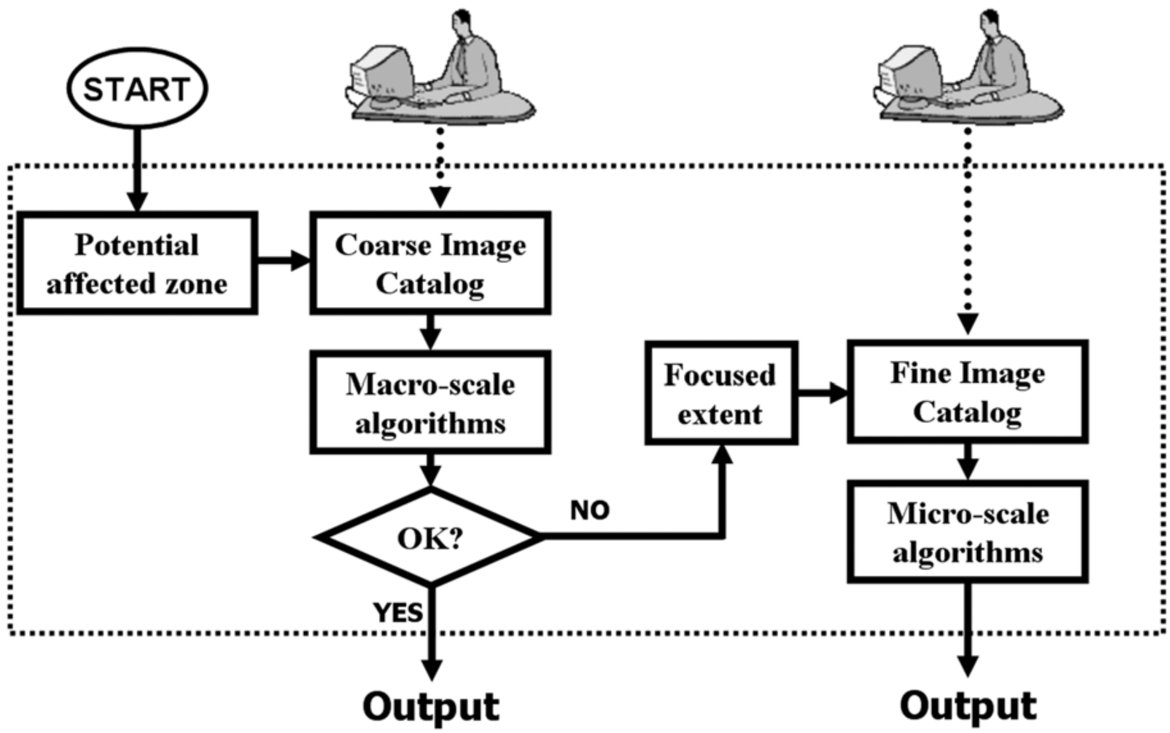

Figure 2. The diagram of proposed system

Theoretically, tsunami is triggered by a big earthquake of over magnitude 6.5 which generates the displacement of seabed. It attacks coastal zones and washes away buildings, trees, etc. along the coastline. The extent of affected areas depends on the topography of the coastal zone as well as the three-dimensional configuration of the seabed. From these observations, we chose medium resolution satellite images like ASTER, Landsat, and SPOT for a coarse scale and high resolution satellite images for a fine scale. The coastline detected from the pre-event scene is used along with a digital elevation model (DEM) to firstly detect the potentially affected areas. Distance and elevation thresholds are required. Comparison of the Normalized Difference Vegetation Index (NDVI) is the main processing on this scale. Details are presented later in Section 3.

On micro-scale, high spatial resolution satellite images such as QuickBird and IKONOS are employed. For a less-than-1m-resolution image of a small focused extent, visual interpretation is applicable. However, an automatic object-based approach was also developed for this detailed mapping. Detailed micro-scale processing is described in Section 4. In both macro-scale and micro-scale processing, several algorithms were developed based on area morphology. Its theory is referred to Vincent (1992) or our previous work (Vu et al. 2005b).

3. MACRO-SCALE PROCESSING

Two ASTER pairs of Khao Lak, Phang-nga Province and Patong, Phuket Province were used to demonstrate the macro-scale processing. Their acquisition dates are shown in Table 1. The coastline was detected by thresholding the near-infrared band or applying the K-mean unsupervised classification followed by the extraction of water class. Using the detected coastline, a proximity analysis with 8-connectivity was carried out to generate a “less than 1.5 km distance” map. This is due to the past experiences that tsunami does not go up farther than this distance once it reaches the land. But we must be careful that tsunami may go up much farther along rivers. The 90 m digital elevation model (DEM) grid derived from Shuttle Radar Topography Mission (SRTM) was also employed. The areas lower than 20 m were selected as potentially affected areas. These two selected classes formed the first draft geographic extent.

Table 1. ASTER images used

Scene	Khao Lak, Phang-nga	Patong Beach, Phuket
Pre-event	November 15, 2002	February 28, 2003
Post-event	December 31, 2004	December 31, 2004

The pre-event and post-event Khao Lak ASTER images in false-color-composite (FCC) are shown in Figures 3a and 3b, respectively. It is easy to observe the affected areas due to massive devastation of vegetation along the coastline. The corresponding NDVI signatures were computed and they are shown in Figures 3c and 3d, respectively. As vegetation was washed away by tsunami, thresholding the difference between pre-NDVI and post-NDVI values shows the potentially affected zones.

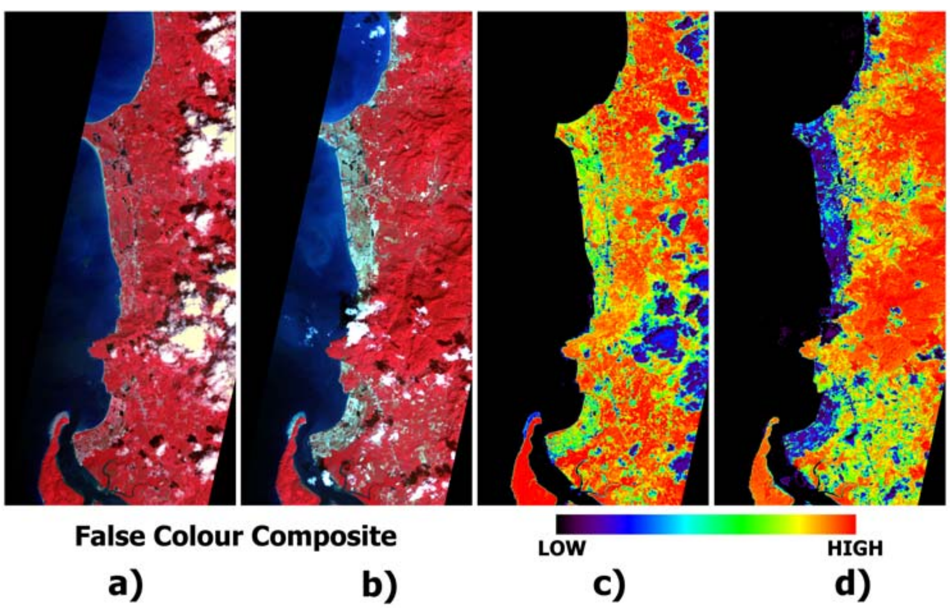

Figure 3. ASTER Khao Lak FCC a) pre-event and b) post-event images; computed NDVI from c) pre-event and d) post-event images.

The extraction affected areas from the pre-event and post-event ASTER images of Patong, Phuket, however, showed no clear difference between the images even though Patong is one of hard-hit areas by tsunami (Figure 4). It implies that it is unable to detect affected areas in Patong using medium resolution satellite images or on macro-scale, in other words. There are a lot of buildings and other structures along the coastline for tourism. The tsunami was blocked by those structures and could not reach very far inland. Although the tsunami destroyed those structures, it was not observed in the medium-resolution satellite images, i.e. top-view. Micro-scale mapping might provide more information.

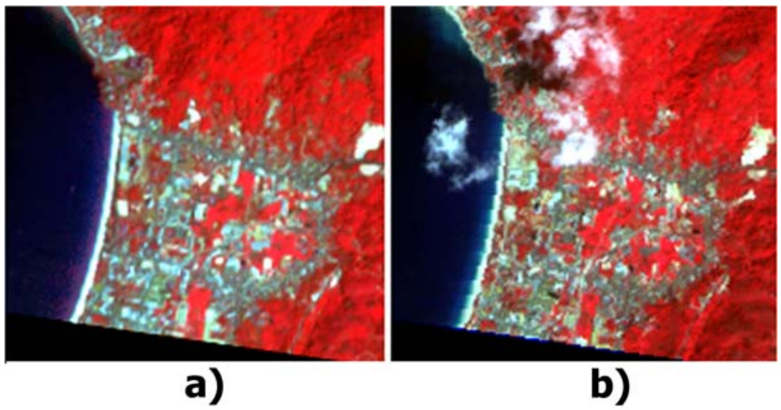

Figure 4. ASTER Patong, Phuket FCC a) pre-event and b) post-event images.

4. MICRO-SCALE PROCESSING

The pre-event and post-event QuickBird images of Patong Beach were purchased as listed in Table 2. These two images were acquired in the same dry season. However, there is a three-year difference in acquisition time which might contain some man-made changes. Furthermore, cloud cover also limits the corresponding extent between two images. The processing method was built on area morphology (Vu et al. 2005b). Prior to that, pan-sharpening was carried out to exploit multi-spectral information at better spatial resolution of 0.6 m instead of 2.4 m.

Table 2. QuickBird images used

Scene	Patong Beach, Phuket
Pre-event	March 23, 2002
Post-event	January 02, 2005

For illustration, Figure 5 shows a selected affected area in false-color-composite (FCC) images. Human perception can easily understand and map the affected areas in the spatial resolution of 0.6 meter. However, the extraction becomes easier with the assistance of information across the scale-space. Based on this way, affected zones can be extracted and overlaid on other layers in further assessment. To detect the changes due to tsunami, it is easier to focus on the changes of vegetation objects and/or soil objects. Extraction was started with vegetation objects (Figures 6a and 6b). Washed-away vegetation can be obtained by logical comparison between Figures 6a and 6b, as resulted in Figure 6c. Vegetation was successfully extracted from the pre-event image and the most part could also be extracted from the post-event image as well. The good point of object-based extraction was that individual stand-alone tree or bush could be extracted as shown in Figure 6b. However, there were several omission errors such as trees and grassland at the bottom of the image due to the shadow of cloud.

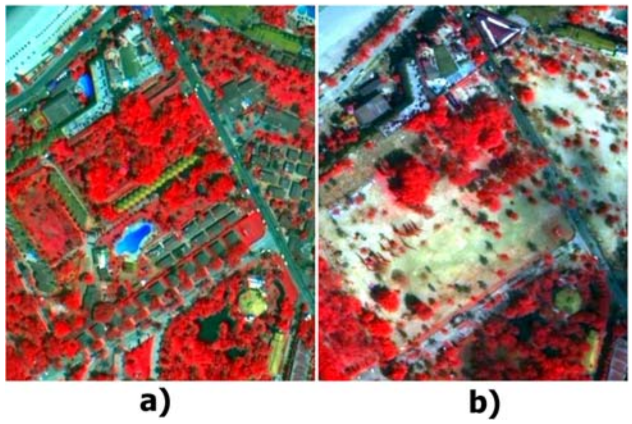

Figure 5. The study area presented in FCC a) pre-event and b) post-event

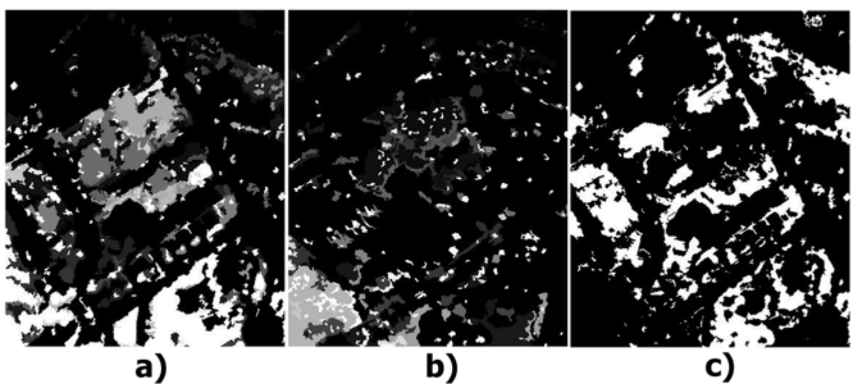

Figure 6. Extracted vegetation from a) pre-event, b) post-event images and c) location of washed-away vegetation in white

Subsequently, soil objects were concerned. There was none of soil objects extracted from the pre-event image as the area was completely covered by grass, tree, streets and houses. On the contrary, the post-event image presented many areas of soil and sand. It is noted that sand has very high reflectance value so that it was classified as bright objects. The extracted results of bright objects and soil objects from the post-event images are shown in Figure 7. Perhaps, these two classified objects might be in the same class but were classified differently due to the intensity. In fact, using only 4 spectral classes, it is unable to further classify different types of soil. Some commission errors were found as several buildings had similar strong reflectance as sand's.

The extracted results show good agreement with the one by visual interpretation. Besides the capability of object-based comparison, it is easy to quickly compute the area of the affected zones. We found that 13,190 m^2 among 24,490 m^2 vegetation including trees and grassland was washed away. Also 26,390 m^2 lands now are covered by sand or mud. It inferred that other objects like buildings were totally collapsed. By further extraction of small buildings from the pre-event images followed by the overlaying with the areas covered by mud/sand from the post-event images, we found 50 destroyed building blocks whose total areas are approximately 9,500 m^2.

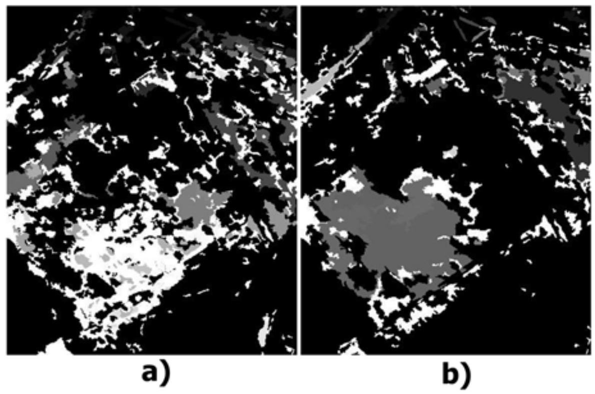

Figure 7. Extracted results from the post-event images a) bare soil and b) bright objects

5. CONCLUSION

Dual-scale mapping idea was introduced and applied to map tsunami-affected areas in Thailand due to the 2004 Indian Ocean tsunami. Dual-scale mapping targets at reduction of cost and processing time for quick response after a catastrophe or to provide a cost-effective solution, in other words. While the macro-scale mapping can provide an affected extent in a large rural area or in a totally devastated area, the micro-scale mapping can provide a detailed change of each object as it possesses higher spatial resolution. In further development of the dual-scale mapping system, GIS-based environment is essential which allows users to connect to the web-based data catalogue for searching for satellite images prior to processing. A web-based catalogue can be searched in local databases of the users or in other agency's databases. The idea would also be applicable to mapping or monitoring other natural hazards like floods, earthquakes etc.

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